Small Autonomous Underwater Vehicle (AUV)
Wave Measurement System

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LONG-TERM GOAL

The primary goal is to develop, demonstrate, and implement techniques for cost-effectively obtaining non-directional and directional ocean surface wave spectra from small AUV's particularly those that are being developed under Office of Naval Research (ONR) sponsorship.

OBJECTIVES

The main objectives of this Phase I Small Business Innovation Research (SBIR) project were: (1) design and specify components of a wave measurement system that can be installed on existing and future small AUV's, and (2) demonstrate feasibility of the overall system, including computer software, by realistic tests and simulations. The objective of an uncompleted Phase I option is to collect and analyze limited preliminary field data. Main objectives of the Phase II effort (FY00-FY01) are to completely design, build, and test prototype systems. Systems would then be used to collect wave data supporting military exercises and scientific investigations such as coastal processes studies.

APPROACH

Use of miniature, low-cost, and low-power hull-mounted pressure sensors was planned and investigated in detail. Measurement of wave pressure, a scalar, involves less sensitive vehicle motion corrections than measurement of wave orbital velocity, a vector. The approach involves correcting pressure data for wave-induced vehicle motion using data from triaxial accelerometers and angular rate sensors that are either already incorporated into small AUV's or that can be added as part of a small wave measurement module. Proving system feasibility involved MATLAB simulations of measured data, AUV motion corrections, and techniques used to estimate wave spectra. A fully operational system conceptual design based on the Florida Atlantic University (FAU) Ocean Explorer (OEX) as an example small AUV was developed to illustrate operational feasibility.

Ronald T. Miles (Neptune Sciences) performed mechanical and electrical engineering work for sensor evaluations and system integration with AUV's. Daniel A. Osiecki (Neptune Sciences) developed and programmed the MATLAB simulations, vehicle motion corrections, and wave analyses. Leon E. Borgman (L.E. Borgman, Inc.) developed non-stationary sensor space array mathematics. Drs. Edgar An, P. Ananthakrishnan, and Samuel M. Smith (all with FAU) provided information regarding AUV operating characteristics and system integration into AUV's.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE **Small Autonomous Underwater Vehicle (AUV) Wave Measurement System**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Neptune Sciences, Inc,40201 Highway 190 East,Slidell,LA,70461**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**3**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

WORK COMPLETED

Phase I feasibility investigations showed that directional wave spectra could be cost-effectively obtained using hull-mounted pressure sensors or narrow beam upward-looking sonars with modified analysis. Mathematics was developed for processing both data types with corrections for wave-induced vehicle motion. Because of low signal to noise ratios from across beam sensors, original measurement and data analysis techniques were developed to estimate directional wave spectra from sensors along a small AUV's bow-stern axis. Determining non-directional wave spectra is easier due to simpler vehicle motion effects and the need for only one sensor.

Obtaining directional spectra involves operating an AUV over easily navigated short paths. Such operation is not needed for large AUV's with suitable signal to noise ratios across the AUV's beam. Corrections were developed for Doppler shifts caused by an AUV's horizontal translational motion. Measurement and analysis techniques were computer programmed and tested using MATLAB simulations. Other approaches, such as measuring wave orbital velocities near an AUV, were shown to involve more complicated instrumentation and more sensitive vehicle motion corrections.

A conceptual design for a fully operational system was developed. The system allows for collecting independent vehicle motion data to facilitate AUV integration. It also allows optional use of vehicle motion data already measured by several small AUV's.

Operating an AUV along paths enables data processing based on theory developed for wave measurement slope arrays. An AUV’s speed must be above a threshold to maintain vehicle heading so that locations of the wave measurements change somewhat with time. Doppler shift corrections are applied. All present techniques for processing wave data by alternative space array methods assume that the sensors are fixed. Because there is no space array analysis technique available to estimate directional wave spectra for non-stationary sensors, the slope array approach was emphasized. New techniques that would be developed during Phase II would allow processing wave data from sensors with known positions that vary with time. These techniques are well suited for small AUV wave measurements. They would implicitly consider vehicle horizontal motion so that Doppler shift effects would not occur and they could provide better wave direction resolution.

RESULTS

Non-directional and directional wave spectra can be obtained using data collected from small AUV’s. While either pressure sensors or upward-looking sonars could be used, use of pressure sensors would be less expensive and have lower power requirements. Developed innovative techniques would enable AUV’s to provide the same types of wave spectra as those obtained from conventional fixed sensors such as pitch-roll-heave buoys and pressure-orbital velocity gages. Investigation of the lack of a space array method for sensors that are not fixed resulted in a new way to estimate high resolution directional wave spectra using sensors whose positions change with time. The fully operational system conceptual design shows that a wave measurement system could be added to almost any small AUV.

IMPACT/APPLICATIONS

Wave measurement capabilities under development would allow waves to be measured from the same small AUV's that ONR is already developing to support littoral military operations and scientific coastal investigations. A mobile AUV wave measurement system could map waves over much larger areas than

can be covered with conventional fixed in-situ instrumentation. Significant spatial variability of coastal waves could be better investigated. Coastal processes models such as surf models could be initialized with system data.

TRANSITIONS

One future transition area is support of littoral military operations that may be adversely affected or limited by waves and resulting surf. Using wave measurement systems with almost any small AUV, including those sponsored by ONR, provides a system transition path to future procurements and operational use.

Another future transition area is using wave measurement systems to support research including coastal processes and beach erosion studies, model initializations and validations, and remote sensing algorithm validations.

RELATED PROJECTS

Techniques employed to correct hull-fixed measurements for vehicle motion utilize data already measured by several small AUV's. Or, when other AUV's are used, data may be acquired and processed by a sensor/electronics module such as that in a Moored Littoral Wave Buoy (MLWB) being developed by Neptune Sciences for the Space and Naval Warfare Systems Command (SPAWAR).

REFERENCES

Earle, M.D., Osiecki, D.A., Miles, R.T., Small Autonomous Underwater Vehicle (AUV) Wave Measurement System, SBIR Phase I Final Report, prepared for Office of Naval Research, Neptune Sciences Inc., Slidell, LA, 51 pp., April, 1999.